5. Operation of Experimental Examples

5.1 Michelson Interferometer

5.1.1 Interference Fringe Observation

<u>He-Ne laser as the light source</u>

Warning:

a) Direct eye exposure to laser is prohibited.

b) <u>DO NOT</u> observe the laser interference fringes using a reflecting mirror.

c) All experiments should be conducted under low-light conditions for better observation of interference phenomena.

1) Place the laser mount with a He-Ne laser mounted in the mounting hole on the side stage and turn on the laser power.
2) Place beam expander in SOCKET2. Adjust the height of the laser tube to make the beam hit the center of the beam expander. Then remove the beam expander.
3) Observe the beam spot on the beam splitter; it should be approximately in the middle of the beam splitter. Also observe the beam spot on the movable mirror. Adjust the laser tube to make the beam spots on beam splitter and movable mirror at the same height.

   Note: This may involve tilting the tube and so remember to re-adjust the height each time tilting occurs. Place a piece of paper card (e.g. Business card) in front of the fixed mirror to avoid multiple reflections.
4) Place a piece of paper card in front of the movable mirror.
5) Place the two-in-one screen in the extension arm in SOCKET1 and let the white screen face towards the beam splitter. A beam spot should be seen on the screen, which is reflected from the fixed mirror. There are also other spots on the screen with less brightness due to multiple reflections. Align the white screen until the brightest beam spot is seen on the center of the screen.

Figure 5 Michelson interferometer with He-Ne laser as light source

6) Remove the cards and observe the white screen. Two bright spots should appear (and less bright multiple reflections). Adjust the movable mirror until the two bright spots coincide with each other at the center of the white screen.
7) Position the beam expander into SOCKET2 with the lens lock facing the beam splitter. If the expanded beam spot is not immediately incident on the movable mirror, then adjust the laser tube. The fringe pattern can be observed on the white screen.

   Note: When adjusting the expanded beam spot, hold a piece of paper behind the movable mirror to identify the location of the beam spot. Adjust the two tilting screws on the laser holder to move the spot onto the movable mirror.

If the observed fringes are not circular, or they are smaller than you may expect, then adjust the presetting micrometer to 'zoom' in or out to get a better view. If no fringes are observed, then repeat the instructions from the beginning; otherwise contact sales@lambdasys.com for technical support.

Sodium lamp as the light source

Figure 6 Michelson interferometer with Sodium lamp as light source

1) Remove the He-Ne laser and beam expander. Place Sodium-Tungsten lamp in the mounting hole (only the Sodium lamp is turned on at this moment).
2) Flip the two-in-one screen to view the interference pattern on the mirror side. Adjust the height of the lamp, so that the sodium light strikes at the center of the mirror. Generally, interference fringes can be observed from the reflected light.

   Note: If fringes are not observed, it means that the interference light path has changed due to vibration when replacing the light source. To retrieve the fringes, the following processes should be taken.

3) Place a pinhole (you can pierce a hole on a business card) in front of the lamp and adjust the movable mirror until the two images of the pinhole coincide with each other.
4) Remove the pinhole and interference fringes should be observed by viewing the mirror. Using the ground glass screen is optional in this experiment, but if in use, it should be inserted between the light source and the beam splitter (SOCKET2).

5.1.2 Equal-Inclination Interference

Now let’s study a different kind of fringes produced by a Michelson interferometer. As shown in Figure 7, **M_2’** is the virtual image of movable mirror **M_2.** In the observer’s field of view, it seems that the two light beams were reflected from mirrors **M_1** and **M_2’** and the interference pattern were produced by a thin air film between **M_1** and **M_2’**.

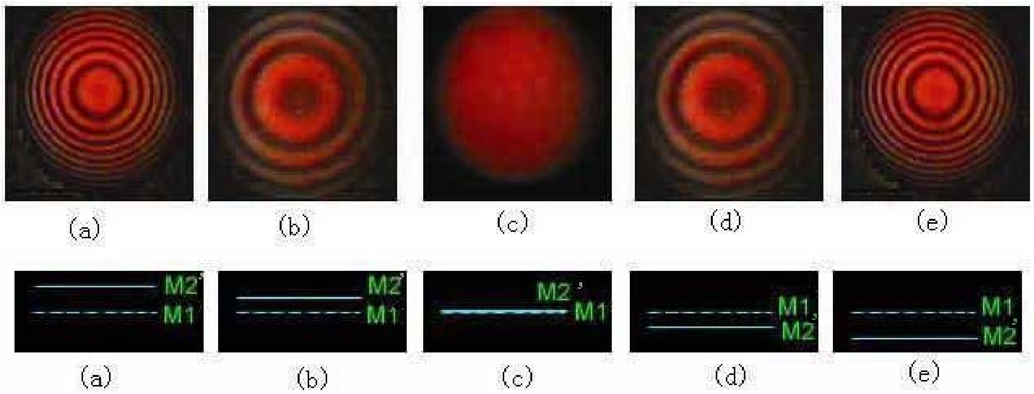


Figure 7 Illustration of equal-inclination interference

<u>He-Ne laser as the light source</u>

1) Re-produce the interference image as per 5.1.1, which should be similar to (a).
2) Adjust the coarse micrometer so that images (a) to (e) are viewed in succession.
3) Set the fine micrometer to the middle of the scale (between 10 mm to15 mm).
4) Re-adjust the coarse micrometer as closely as possible to reproduce image (c).
5) Use the fine micrometer to produce fringes of equal inclination.

5.1.3 Equal-Thickness Interference

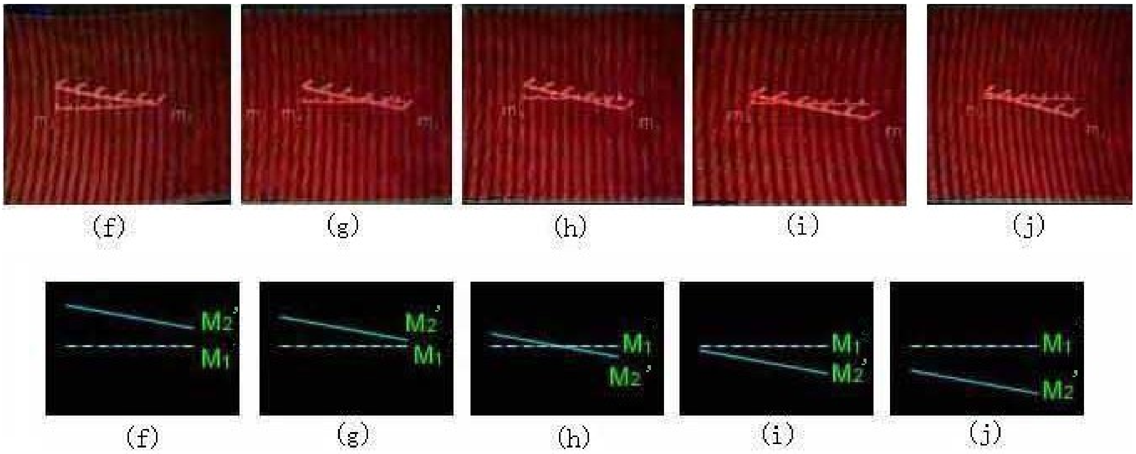


Figure 8 Fringes of equal thickness

Adjust the tilt screws at the back of $\mathbf{M_2}$. If $\mathbf{M_1}$ and $\mathbf{M_2'}$ are tilted with a very small angle with each other, the fringes of equal-thickness interference can be observed on the screen.

<u>He-Ne laser as the light source</u>

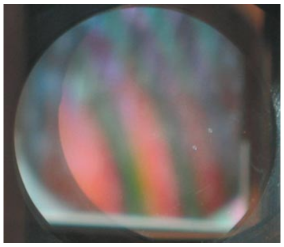
1) Install the He-Ne laser and remove the beam expander. Set the fine micrometer to the middle of the scale (between 10 mm to15 mm).
2) Adjust the laser and movable mirror to get interference pattern on the white screen.
3) Turn the coarse micrometer in the direction which interference rings collapse at the center, and then the fringes expand. Stop when there are only a few fringes on the screen.
4) Turn the fine micrometer to move the movable mirror in the direction which interference rings collapse at the center, until there are only two or three rings left.
5) Adjust the movable mirror slightly. If the image of movable mirror M_2' is tilted relative to the fixed mirror M_1, interference stripes should be observed.
6) Continue to turn the fine micrometer to make the curved fringes move toward their center. Some straight bands will appear in succession. Those are the fringes of equal-thickness interference.

5.1.4 White-Light Interference Fringes

Because white light has a short coherence length, interference fringes from white light can only be observed when the optical-path difference is close to zero. Compared to the interference pattern created by a laser or a Sodium lamp, white light interference is much more difficult to produce. With the help of a specially designed Sodium-Tungsten lamp, zero path difference can be easily obtained for the observation of white-light interference.

Figure 9 Michelson interferometer with Sodium-Tungsten lamp as light source

1) After achieving equal-inclination interference (5.1.2), replace the laser with the Sodium- Tungsten lamp and remove the beam expander. Use the mirror of the two-in-one screen as the observation screen.



2) Adjust the height of the light source until the yellow Sodium light and white Tungsten light illuminate the upper and lower half of the viewing field, respectively. Make sure that the visible Sodium fringes have good contrast and wide-spacing. Interference fringes of Sodium doublet may help locate the point of zero path difference.

   Note: If no fringes are observed, it means that the interference light path has changed due to vibration when replacing the light source. To retrieve the fringes, the following processes should be taken.

3) Place a pinhole (you can pierce a hole on a business card by a pin) in front of the lamp and adjust the movable mirror until the two images of the pinhole coincide with each other. Now interference fringes should be seen in the viewing mirror.

4) To search for white light fringes, turn the fine micrometer slowly to maintain the yellow fringes in the field of view. Otherwise, the condition of zero path difference and hence the production of white light fringes might be missed if the fine micrometer were turned too fast.

5) This way color fringes will continue to appear, and at a moment, an interference fringe pattern with a dark center will be observed. That is the white-light interference at the position of zero light-path difference.

6) To observe the white-light interference fringe clearly, the Sodium lamp should be turned off and the ground glass screen should be put in SOCKET2.

5.1.5 Measurement of the Wavelengths of the Sodium D-lines

Figure 10 Michelson interferometer with Sodium-Tungsten lamp as light source

1) Place the Sodium-Tungsten lamp on the side-stage and warm it up for about 5 minutes.

2) Adjust the interferometer to produce circular fringes in the field of view.

3) At the position with a clear equal-inclination fringes, record the reading d_0 of the fine micrometer.

4) Count the number of fringes that expand (or collapse) in the center of the field of view as the fine micrometer is turned slowly (using the provided manual counter). After counting 50 fringes, record the micrometer reading again.

5) Continue the above process through 250 fringes, and record the micrometer reading after each set of 50 fringes has been counted. Calculate the actual mirror movement, Δd , as

$$\Delta d = \frac{\Delta N \lambda}{2}$$

where λ is the wavelength of the source and ΔN is the number of fringes counted. On the other hand, the wavelength of the source can be determined by

$$\lambda = \frac{2\Delta d}{\Delta N}$$

Alternatively, one can plot Δd vs ΔN, and conduct linear curve-fitting to the data, the fitted slope is $\lambda/2$.

Notes:

a) Always turn the micrometer knob in one direction.
b) Set the micrometer screw somewhere near the middle of its travel. In this position, the relationship between the micrometer reading and the mirror movement is nearly linear.
c) Turn the micrometer a full turn before counting fringes to eliminate backlash errors.
d) Actual mirror movement is the scale interval of the fine micrometer divided by a factor of 40.

5.1.6 Measurement of the Wavelength Separation of the Sodium D-lines

The Michelson interferometer can also be used for measurement of the wavelength separation of the Sodium D-lines. The yellow Sodium doublet consists of two spectral lines with a small wavelength separation between them. Therefore, when a Sodium lamp is used as the light source in a Michelson interferometer, the interference fringes produced by two yellow lines will appear periodically (clear and blurry) as the movable mirror is moved continuously. The wavelength difference of the yellow sodium doublet lines is given by

$$\Delta \lambda = \frac{\bar{\lambda}^2}{2\Delta d}$$

Where $\bar{\lambda}$ is the averaged wavelength of the two lines through the result of last experiment, Δd is the thickness of the air membrane between mirrors $\mathbf{M_1}$ and $\mathbf{M_2}$**’**.

1) Adjust the interferometer to obtain a clear, wide-spaced interference pattern of Sodium doublet. Slowly turn the fine micrometer till all the fringes disappear. Record the reading d_1 of the micrometer;
2) Continue to turn the micrometer in the same direction and new interference pattern appears. Record the reading d_2 where the interference pattern vanishes again;
3) Repeat this process in different places near zero path difference point to get an average value of $\Delta d = |d_1 - d_2|$.

5.1.7 Refractive Index of Air

In Michelson interferometer mode, if an air chamber is placed in the light path of **M_2** and then the air density in the chamber is altered by deflating or pumping the air in the chamber, the optical-path length will change by δ. Accordingly, a certain number of interference fringes will pass through the viewing point.

$$\delta = 2\Delta nl = N\lambda$$

Therefore,

$$\Delta n = N\lambda / 2l$$

Where, l is the length of the air chamber, λ is the wavelength of the light source, N is the number of fringes counted to pass through the viewing point.

The refractive index of air is dependent upon its temperature and pressure. If n is near unity, then n-1 is directly proportional to density ρ of the gas. For ideal gas:

$$\frac{\rho}{\rho_0} = \frac{n-1}{n_0 - 1}$$

If T is the absolute temperature, P is the pressure. Then,

$$\frac{\rho}{\rho_0} = \frac{PT_0}{P_0 T}$$

Thus,

$$\frac{PT_0}{P_0 T} = \frac{n-1}{n_0 - 1}$$

If the temperature is constant, then

$$\Delta n = \frac{(n_0 - 1)}{P_0} \Delta P$$

Because $\Delta n = N\lambda / 2l$, then

$$\frac{(n_0 - 1)}{P_0} \Delta P = N\lambda / 2l$$

Therefore

$$n_0 = 1 + \frac{N\lambda}{2l} \times \frac{P_0}{\Delta P}$$

Figure 11 Michelson interferometer with air chamber in optical path

1) Align the interferometer.
2) Adjust the movable mirror $\mathbf{M_2}$ to obtain clear equal-inclination fringes on the center of the white screen using a He-Ne Laser.
3) Put the air chamber with known length l in its holder (for accurate measurement, the end plates of the air chamber must be perpendicular to the laser beam).
4) Pump in air to the chamber and then record the reading of the gauge ΔP .
5) Release the valve and slowly deflate the air in the chamber till the gauge reads zero. During the process, count N (using the provided manual counter). The refractive index of air in the experiment is given by,

$$n_0 = 1 + \frac{N\lambda}{2l} \times \frac{P}{\Delta P}$$

where P_0 is the atmospheric pressure (101.325 kPa); l=80 mm.

Note: This experiment should be carried out several times in order to get the average.

Notice: To protect the gauge, the reading of the gauge should not be over 40 kPa.

5.1.8 Refractive Index of Transparent Slice

When a transparent slice is placed in one optical arm of the Michelson interferometer, the light path of this arm changes as the transparent slice rotates. The difference of the light path can be determined by counting the number of the fringes collapsed or expanded. If the entrance light is perpendicular to the end plate of the transparent slice initially, the refractive index of the slice can be measured by counting the number of fringes passed through while rotating the slice. The refractive index of the slice, n , is given by:

$$n = \frac{n_0^2 d \sin^2 \theta}{2n_0 d(1-\cos\theta) - N\lambda}$$

Where λ is the wavelength of the light source (the He-Ne laser), n_0 is the refractive index of air, θ is the rotating angle of the slice, d is the thickness of the slice, and N is the number of fringes counted when the slice is rotated by angle θ.

Figure 12 Michelson interferometer with transparent slice in optical path

Experimental Procedure

1) Place the clip for the transparent slice in the mounting hole in SOCKET3.
2) Place the two-in-one screen on the extension arm and adjust the screws at the back of the movable mirror to get a set of clear fringes on the white screen.
3) Mount the transparent slice on the clip. Adjust the clip and the rotational pointer. Make sure that the slice is approximately perpendicular to the optical path.
4) Slowly rotate the clip using the pointer while monitoring the fringes on the screen carefully. During the process, the fringes in the center of the screen will collapse or expand. Stop rotating when the fringes neither collapse nor expand. Now the slice is set perpendicular to the optical path.
5) Adjust the movable mirror to get a set of clear fringes on the screen. Slowly rotate the slice by moving the lever arm. Count the number of fringe transitions as the slice is rotated from its original angle set in step 4 to its new angle (at least 10 degrees). If the rotating angle is θ and the number of fringes counted is N, then the refractive index of the slice, n, is given by the equation:

$$n = \frac{n_0^2 d \sin^2 \theta}{2n_0 d(1-\cos\theta) - N\lambda}$$

   Where n_0 is the refractive index of air (see Experiment above), λ is the wavelength of the He-Ne laser in vacuum, N is the number of fringe transitions counted, and d is the thickness of the transparent slice (d = 0.1 mm).

6) Repeat steps 4, 5 and 6 three times and calculate the average of *n*.

5.2 Fabry-Perot Interferometer

5.2.1 Multi-Beam Interference

1) Turn the interferometer by 90° to make the Fabry-Perot interferometer facing the observer at the position opposite to the movable mirror.
2) Unscrew the F-P mirror (i.e. Item 8 in Figure 4), and then mount it in the holes in front of the movable mirror (Item 11). Make the front surface of F-P mirror face towards the movable mirror.
3) Adjust the three screws behind the movable mirror to make sure that the two mirrors are parallel to each other approximately with a distance of about 2 mm.
4) Unscrew the screw on the top of the beam splitter and compensator and remove the whole beam-splitter/compensator assembly. Put it in a safe place (mounting it in the place of the fixed mirror is a good choice).
5) Set up the He-Ne laser in the light path of the Fabry-Perot interferometer. Adjust the laser to make the laser beam hit the center of the F-P mirror. Adjust the top and right screws behind the movable mirror to make the beam spots coincident (one can place the beam expander in front of the He-Ne laser while observing the comet-like light spots behind the movable mirror and adjusting the screws of the movable mirror until the comet-like spots shrink to minimum in all directions).
6) Now the two mirrors are near parallel and a series of multi-beam interference rings can be observed behind the movable mirror with a naked eye, as shown in Figure 13. (**Warning**: **Avoid mirror contact or collision at all times**).

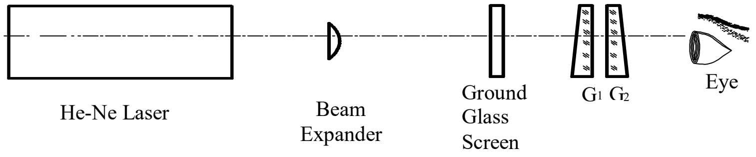


Figure 13 Diagram of Fabry-Perot interferometer mode

If **G_1** and **G_2** are absolutely parallel to each other, the interference fringes on the ground glass screen will have a perfect circle shape as shown in Figure 14 (the ground glass screen should be mounted in the extension arm and placed behind the movable mirror, see dotted lines in the structural figure shown in Figure 4).

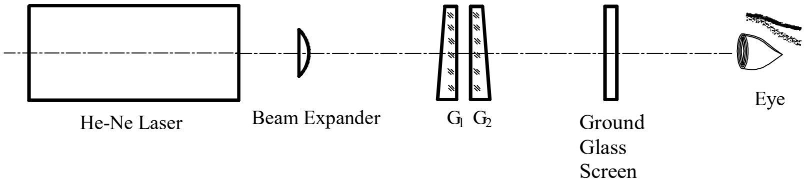


Figure 14 Diagram of Fabry-Perot interferometer mode with ground glass screen mounted in extension arm and placed behind movable mirror

5.2.2 Measurement of the Wavelength of a He-Ne Laser

The interference fringes of F-P interferometer are clearer and thinner than those of Michelson interferometer. As a result, by using the same *fringe-counting* method with an F-P interferometer, the wavelength of a He-Ne laser can be measured more accurately.

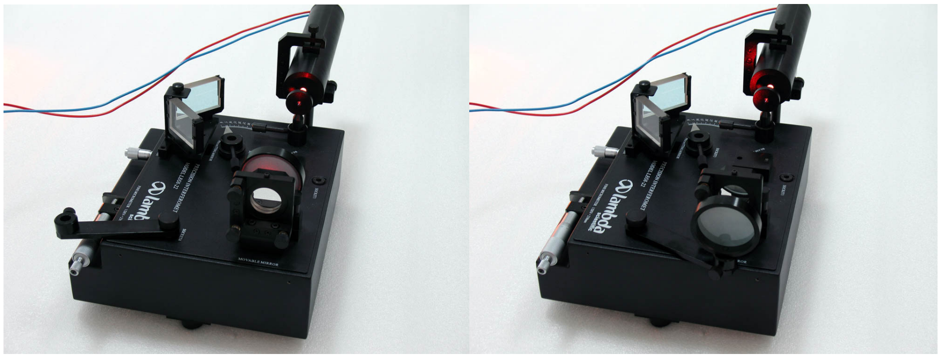


Figure 15 Fabry-Perot interferometer mode

1) Setup the F-P interferometer.
2) Adjust the interferometer carefully to produce clear circular fringes in the center of ground glass screen.
3) Record the reading d_0 of the fine micrometer.
4) Count the number of fringes that expand (or collapse) in the center of the ground glass screen as the micrometer is turned slowly (using the provided manual counter). After counting 50 fringes, record the micrometer reading again
6) Calculate Δd. The actual mirror movement Δd is given by

$$\Delta d = \frac{\Delta N \lambda}{2}$$

Here λ is the wavelength of the source, ΔN is the number of fringes counted, and ΔN equals 50. On the other hand, the wavelength of the light source can be determined as

$$\lambda = \frac{2\Delta d}{\Delta N}$$

7) To minimize any errors in counting the rings or recording the micrometer reading, steps 1- 6 should be repeated at least 3 times.

5.2.3 Observation of the Interference of the Sodium D-lines

If a low-pressure Sodium lamp is used as the light source in an F-P interferometer, two different sets of concentric interference fringes can be observed on the ground glass screen, as produced by the light emitted from a Sodium lamp with two different wavelengths. By turning the fine micrometer continuously, the two sets of interference fringes coincide at certain micrometer settings and separate at other settings.

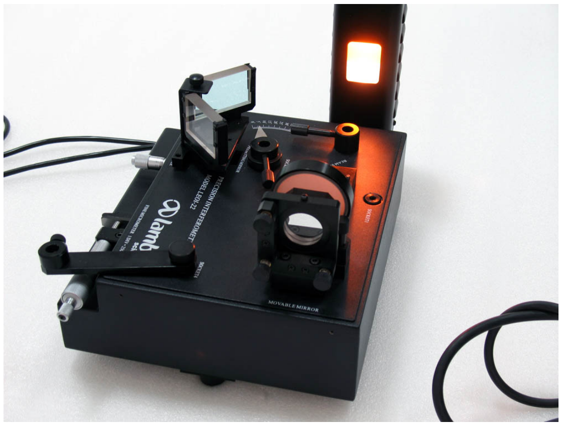


Figure 16 Fabry-Perot interferometer with Sodium lamp as light source

1) Setup the instrument in F-P mode. Use the Sodium lamp as the light source and turn it on.
2) Slowly move the movable mirror by adjusting the fine micrometer till the two mirrors are very close to each other. (The distance between them should be about 1-2 mm. Do not let them touch each other).
3) Place a pinhole plate in front of the lamp. Generally, the light beam passing through a hole in front the lamp forms a series of light spots due to the reflections of the two mirrors or they may look like a comet's tail. Adjust the movable mirror to make those spots coincide.
4) Remove the pinhole plate and adjust the movable mirror carefully till clear interference fringes are observed. For the convenience of observation, the ground glass screen should be used in the mounting hole in front of F-P mirror (Fixed Mirror).
5) Slowly turn the fine micrometer to observe the Separating- Coinciding- Separating phenomenon of the interference fringes.

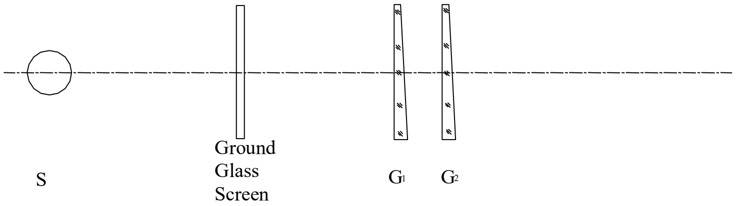


Figure 17 Diagram of Fabry-Perot interferometer mode with Sodium lamp as light source

Note: Be careful when adjusting the fine micrometer of the movable mirror. Avoid the collision of the two mirrors.

5.3 Twyman-Green Interferometer

5.3.1 Demonstrating the Principle of a Twyman-Green Interferometer

Twyman-Green interferometer is used to check optics by parallel light. Following figures are the common configurations of a Twyman-Green interferometer in checking modes.

a) Check flat mirror

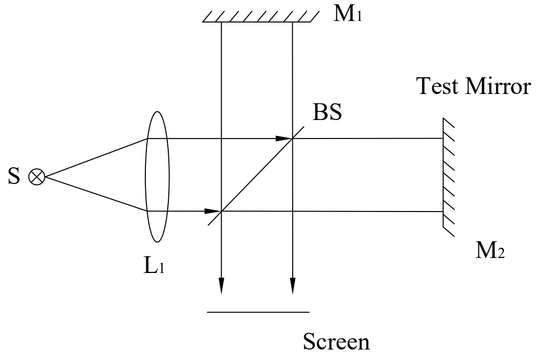


Figure 18 Configuration of Twyman-Green interferometer for checking flat mirror

Figure 18 shows the configuration diagram of a Twyman-Green interferometer for checking a flat mirror. If the mirror under test has any defects, the corresponding fringes can be observed on the screen.

b) Check transparent flat optic

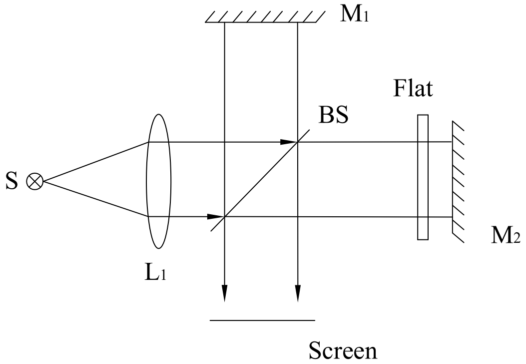


Figure 19 Configuration of Twyman-Green interferometer for checking transparent flat optic

Figure 19 shows the configuration diagram of a Twyman-Green interferometer for checking a transparent flat optic. If the flat optic under test has any defects, the corresponding fringes can be observed on the screen.

c) Check prism

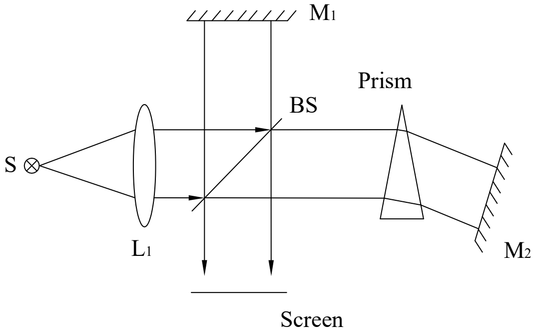


Figure 20 Configuration of Twyman-Green interferometer for checking prism

Figure 20 shows the configuration diagram of a Twyman-Green interferometer for checking a prism. If the prism under test has any defects, the corresponding fringes can be observed on the screen.

d) Check lens

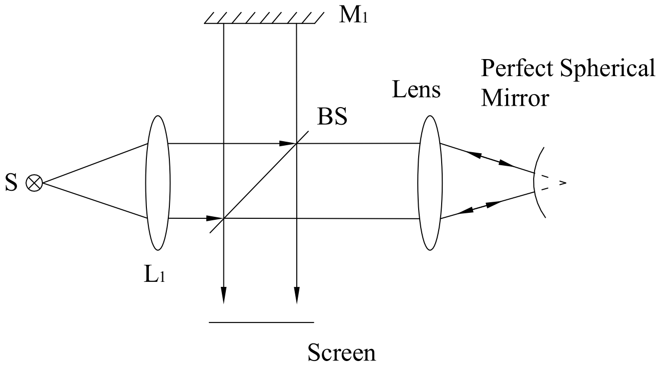


Figure 21 Configuration of Twyman-Green interferometer for checking lens

Figure 21 shows the configuration diagram of a Twyman-Green interferometer for checking a lens. If the lens under test has any defects, the corresponding fringes can be observed on the screen.

Notice:

This instrument is designed to demonstrate the checking principles of a Twyman-Green interferometer ONLY and it is NOT designed for practical optical tests. Here we use mode b), and with the help of expand light source (laser and beam expander) to demonstrate the principle.

Experimental Procedure

Figure 22 Twyman-Green interferometer configured for checking transparent flat optic

1) Set up the instrument according to the Michelson interferometer. He-Ne laser is used as the light source.
2) Adjust the movable mirror to get equal-thickness fringes on the screen. Refer to the particular procedures described in experiment 5.1.3.
3) Place the thin film (Sample 1 and sample 2 in turn) into the clamp and set them in SOCKET3.
4) Observe the interference fringes on the screen. If the sample has perfectly flat surfaces the fringes are perfect too. Otherwise the fringes will have the corresponding deformation and tortuosity.